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RESEARCH MEMORANDUM

NOTE ON THE EFFECTS OF FIRST-ORDER AERODYNAMIC LOADS ON PROPELLER SHAFT LOADS WITH EMPHASIS ON COUNTERROTATING PROPELLERS

By Vernon L. Rogallo, John L. McCloud III, and Paul F. Yaggy

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RESEARCH MEMORANDUM

NOTE ON THE EFFECTS OF FIRST-ORDER AERODYNAMIC LOADS ON PROPELLER SHAFT LOADS WITH EMPHASIS ON COUNTERROTATING PROPELLERS

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SUMMARY

It is pointed out that to determine the shaft forces and moments for propellers having flexible blades, it may not be sufficient to examine only the aerodynamic loads on the blades. For a propeller operating near blade resonance, the system is a vibratory one in which dynamic effects, such as phase shifts and amplification changes, can occur. The dynamic phenomena are of particular importance in analysis of counterrotating propellers since shaft moments which heretofore have been considered self-canceling may be present and of considerable magnitude.

INTRODUCTION

The present trend in propeller design is toward highly flexible blades absorbing high powers. This trend may give rise to shaft loads of greater magnitude than would be expected on the basis of usual analyses, in particular for the case of counterrotating propellers. Possible evidence of this may exist in the experience recently encountered when, on a counterrotating propeller, the measured propeller shaft loads were greater than twice the loads computed by existing methods. Of particular concern here are the shaft loads which result from angle of inclination of the propeller shaft with respect to the air stream. An investigation being made at Ames Laboratory of the 1×P excitation of inclined single-rotation propellers has indicated a new concept for determining propeller shaft forces and moments (i.e., normal and side forces, and pitching and yawing moments) of an inclined propeller. The purpose of this report is to present preliminary results of this analytical investigation, in particular with respect to the counterrotating propeller.

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THEORY

The moments exerted on the airframe through the propeller shaft are due to the 1XP sinusoidal thrust variation, and the forces normal to the propeller shaft are due to the 1XP sinusoidal torque variation. The normal and side forces and pitching and yawing moments are functions of both the magnitude and angular position of the peak blade reaction loads (i.e., the loads transmitted to the propeller shaft), as shown in figure 1. These reaction loads are, in turn, dependent on the magnitude and angular position of the peak blade aerodynamic loads. For a propeller operating well below blade resonance, the blade aerodynamic loads and the blade reaction loads are essentially in phase and of equal magnitude. For this condition, the forces and moments have been satisfactorily predicted by existing methods (e.g., refs. 1 and 2). For a propeller operating near blade resonance, the blade aerodynamic loads and the blade reaction loads would be expected to differ in phase and in magnitude. This is suggested by analogy with the classic spring-mass resonance phenomenon which gives rise to amplification and angular phase shift between applied and reaction loads.

It is well known that inclination of the thrust axis of a propeller produces 1XP aerodynamic thrust loads. Similarly, 1XP aerodynamic torque loads are produced which are essentially in phase with the thrust load. The magnitudes and angular positions of the peaks of these loads are related to the angle of inclination. For the case of angle of attack, the angular positions of the peak loads are at 90° and 270° whereas for angle of yaw they are at 0° and 180°.[1] Thus, for operation well below resonance, the oscillating loads produce a normal force and yawing moment for angles of attack and a side force and pitching moment for angles of yaw. Near resonance the blade aerodynamic loads still peak near the 90° position for angle of attack, and 180° for yaw, but the blade reaction loads peak later and are magnified by the resonance phenomenon. Figure 2 shows the blade thrust reaction loads assuming both well-below-resonance and near-resonance conditions for propellers at an angle of attack. The well-below-resonance condition produces a yawing moment since the blade reaction and blade aerodynamic thrust loads are in phase. In the near-resonance condition, the reaction load is lagging (in time) and is greater (in magnitude) than the aerodynamic load. In this case the blade reaction loads are producing a moment that has both pitching and yawing components. Similarly, the pitching moment due to yaw will be rotated and amplified by resonance to produce a moment that has both pitching and yawing components. The torque loads are also amplified in the near-resonance condition and the reactive torque loads are shifted in phase. Thus, the forces on the shaft will be shifted in phase and amplified; the resulting forces and moments on a propeller in pitch and/or yaw are given by

[1]These angles are measured in the direction of propeller rotation from the uppermost vertical position.

[redacted]

$$(NF) = (NF)_o A \cos \varphi \mp (SF)_o A \sin \varphi \quad (1)$$

$$(SF) = (SF)_o A \cos \varphi \pm (NF)_o A \sin \varphi \quad (2)$$

$$(YM) = (YM)_o A \cos \varphi \pm (PM)_o A \sin \varphi \quad (3)$$

$$(PM) = (PM)_o A \cos \varphi \mp (YM)_o A \sin \varphi \quad (4)$$

The upper signs are for right-hand propeller rotation viewed from the rear and the standard NACA sign convention is employed. The quantities are defined by

NF vertical force normal to propeller shaft
SF horizontal force normal to propeller shaft
PM moment about horizontal propeller-plane axis
YM moment about vertical propeller-plane axis

Subscript o denotes the value obtained for the nonresonant condition.

A amplification factor
φ phase angle

Implicit in equations (1) to (4) are the following important assumptions:

1. All the blade reaction load is amplified and shifted in phase. Actually, only that component of the blade reaction load that is in the plane of resonant motion will be amplified and shifted in phase.

2. Any effects on the shaft forces due to radial loads which may arise as a result of the blade motion may be neglected.

Further, in order to illustrate the implications of this analysis, it is assumed the parameters $A \cos \varphi$ and $A \sin \varphi$ for the propeller are similar to those for a single degree of freedom spring-mass system with viscous damping and are as shown in figure 3. It is not known to what degree the phase angle and amplification factor for this system are applicable to propeller blades.

Insofar as the single-rotation propeller is concerned, these dynamic effects are important because of their obvious effects on stability and on the resulting amplified structural loads. In the case of the counter-rotating propeller, it will be seen that these effects are of even more importance in regard to the structural loads. It has been generally assumed that the 1XP thrust variations for the front and rear propeller units, which are essentially equal in magnitude, peak at diametrically opposite positions and, therefore, their moments cancel each other. For

the well-below-resonance condition, this is a reasonable first-order approximation. However, when resonance is approached, this assumption is no longer valid. As an example, figure 4 shows, for an angle of attack, the blade thrust reaction loads and resulting shaft moments for both units of a counterrotating propeller for the well-below-resonance and near-resonance conditions. It may be noted that in the well-below-resonance condition the moments are equal and opposite and produce a zero shaft moment aft of the propeller. However, as resonance is approached, the angular positions of the peak blade reaction loads are each rotated in the direction of propeller rotation and the loads are amplified. Although the yawing components of the resulting moments cancel each other, the pitching components of these moments are additive. Figure 3 shows that, for a damping-constant ratio of 0.5 or less and at frequency ratios above 0.8, $A \sin \varphi$ may exceed 1. The resulting pitching moment would be as great or greater than twice the yawing moment which existed on each unit in the well-below-resonance condition. Thus, although at the well-below-resonance condition pitching-moment components do not exist, as resonance is approached, a considerable pitching moment will exist. The shaft forces on the counterrotating propeller are rotated and amplified in a similar manner. Thus, for the case of pitch, the side forces would cancel each other, but the normal forces would remain additive and subject to an amplification factor.

CONCLUDING REMARKS

In conclusion it may be stated that for propellers having flexible blades, it is not sufficient to examine only the aerodynamic loads on the blades to determine the shaft forces and moments. The dynamic effects including amplification and phase shift must also be included. This dynamic phenomena is of particular importance in analysis of counterrotating propellers since shaft moments, which heretofore have been considered self-canceling, may be present and of considerable magnitude.

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, Calif., Mar. 30, 1954

REFERENCES

1. Glauert, H.: Airplane Propellers. Vol. IV of Aerodynamic Theory, div. L, W. F. Durand, ed., Julius Springer (Berlin), 1935, pp. 351-359.

2. Ribner, Herbert S.: Propellers in Yaw. NACA Rep. 820, 1945.

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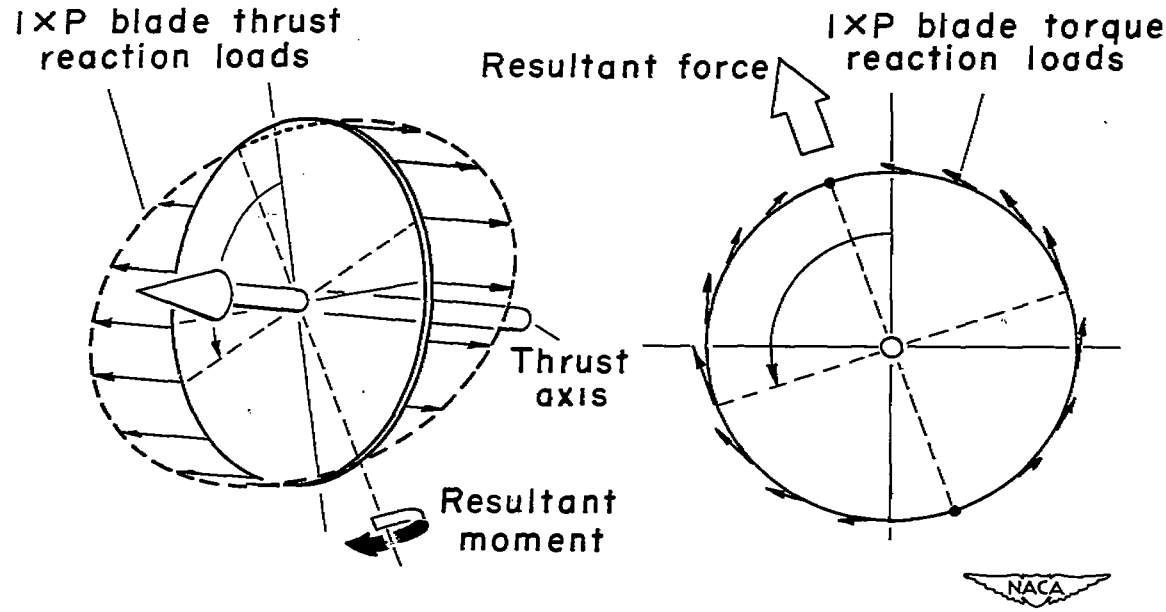


Figure 1.—Schematic representation of the 1×P sinusoidal thrust and torque blade reaction loads and the resulting shaft moments and forces.

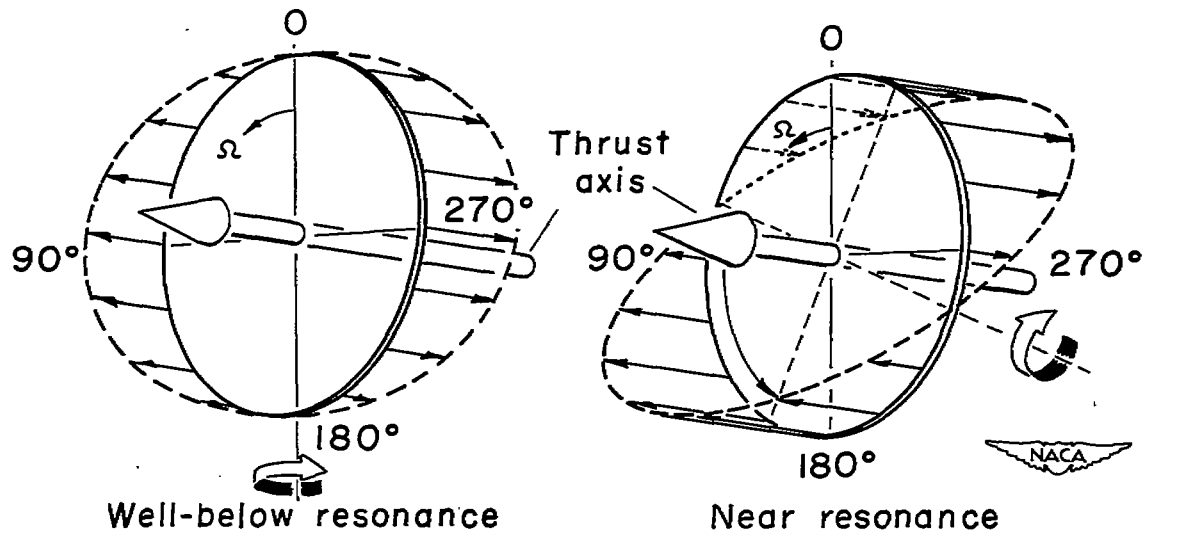


Figure 2.—Schematic representation of the 1×P sinusoidal blade thrust reaction loads and resulting moments of a single propeller for the well-below- and near-resonance conditions.

[redacted]

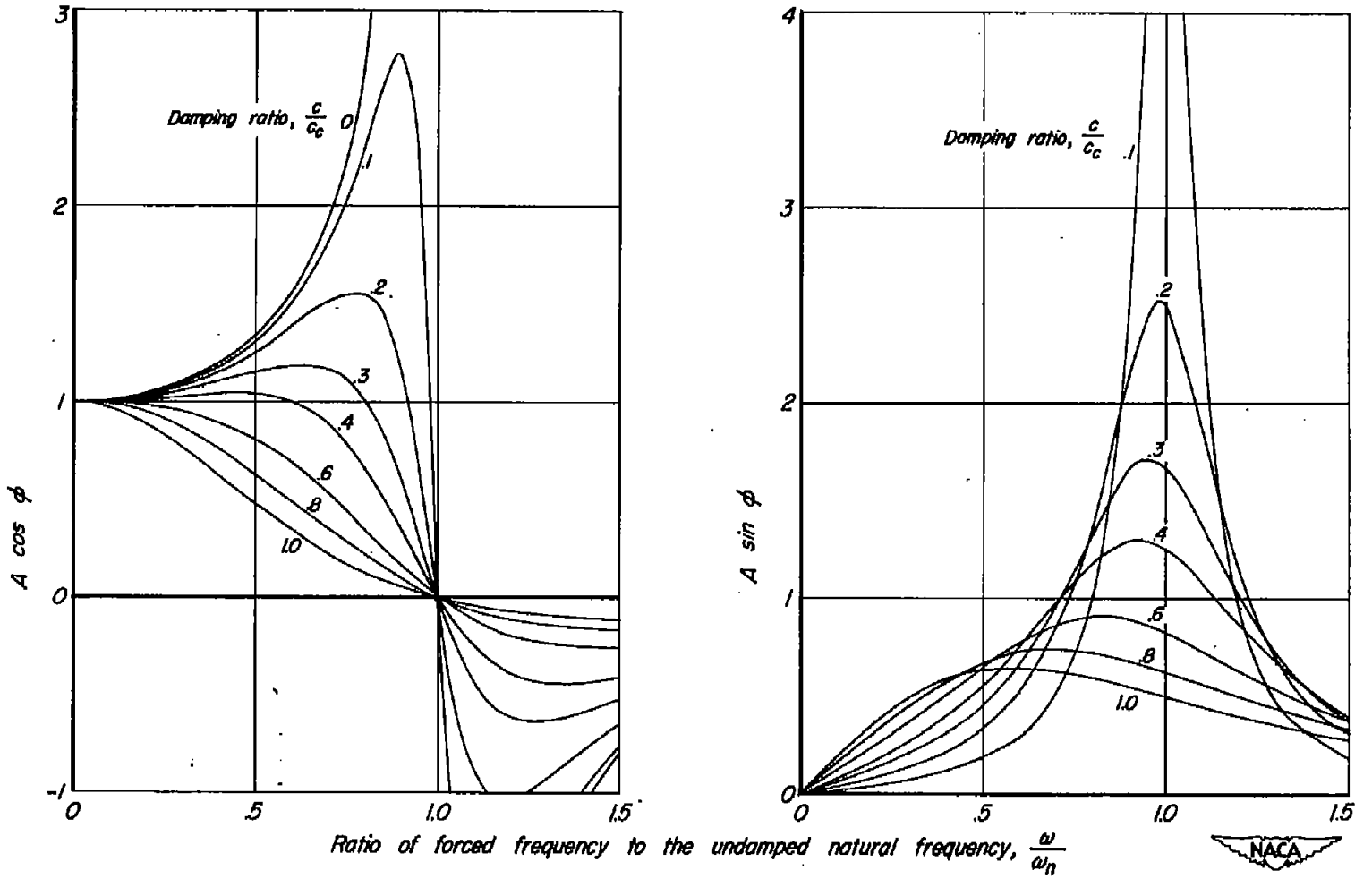
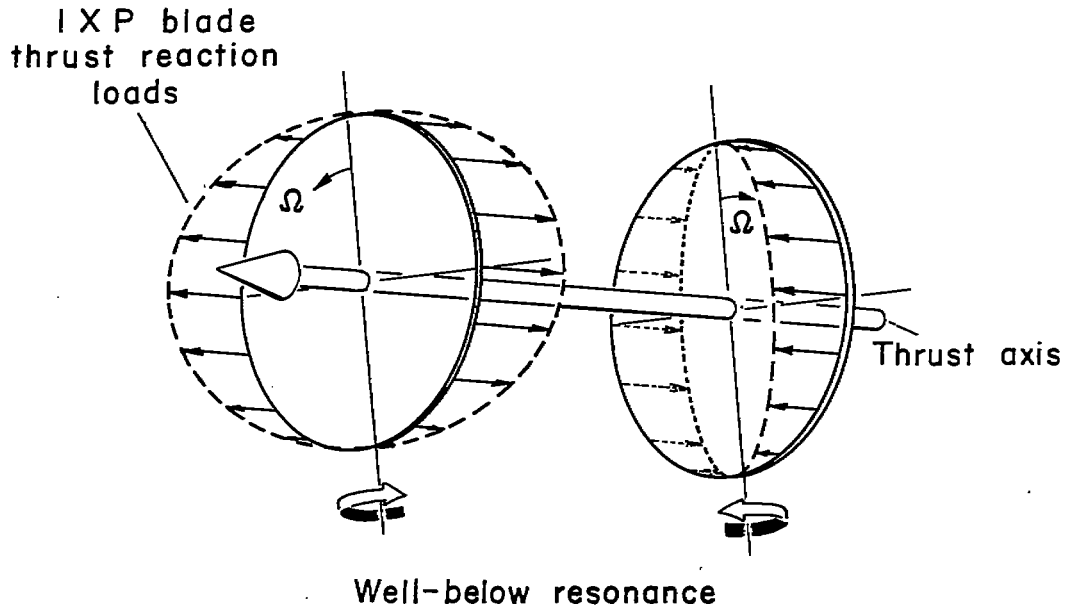


Figure 3.— Variation of the parameters A cos ϕ and A sin ϕ with frequency ratios for a single degree of freedom spring-mass system with various amounts of viscous damping.



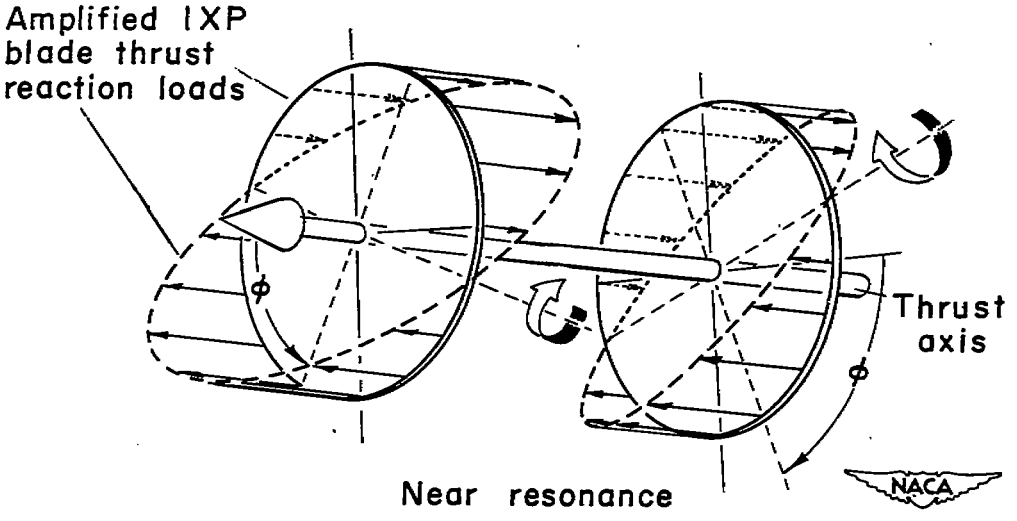


Figure 4.- Schematic representation of the 1 X P sinusoidal thrust blade reaction loads and resulting moments of a counter-rotating propeller for the well-below- and near-resonance conditions.

SUBJECT HEADINGS

Propeller Theory	1.5.1
Propellers, Dual Rotation	1.5.2.7
Propellers, Pitch and Yaw	1.5.2.9
Propeller Operating Conditions	1.5.6
Stability	1.8.1
Loads - Fuselage, Nacelles, and Canopies	4.1.1.3
Vibration and Flutter - Rotating Wing Aircraft	4.2.5

ABSTRACT

It is pointed out that to determine the shaft forces and moments for propellers having flexible blades, it may not be sufficient to examine only the aerodynamic loads on the blades. For a propeller operating near blade resonance, the system is a vibratory one in which dynamic effects, such as phase shifts and amplification changes, can occur. The dynamic phenomena are of particular importance in analysis of counter-rotating propellers since shaft moments which heretofore have been considered self-canceling may be present and of considerable magnitude.

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